Adaptive XR Rehab with Haptic Feedback and Dynamic Difficult Adjustment

Antonio Luigi Stefani
University of Trento - Department of Information Engineering and Computer Science
Via Sommarive , 9 I-38123 Povo (TN), Italy
antonioluigi.stefani@unitn.it

Overview. This demo presents an innovative framework that integrates touch perception and Dynamic Difficulty Adjustment (DDA) in eXtended Reality (XR) environments to support hand dexterity rehabilitation. The demo addresses two main research challenges: (1) enhancing the fidelity of XR experiences through tactile feedback, and (2) leveraging gamification strategies to adapt exercise difficulty to the patient's abilities, creating a smart level selector that supports a controlled and progressive improvement of motor capabilities.

In this context, haptic feedback enables a more realistic modeling of the surrounding environment by adding a tactile stimulus, encouraging users to act in a more natural way. Gamification contributes in two ways: (i) it creates a more engaging experience by adapting difficulty to the user's capabilities, and (ii) it provides cognitive stimulation by keeping the user in a state of appropriate challenge.

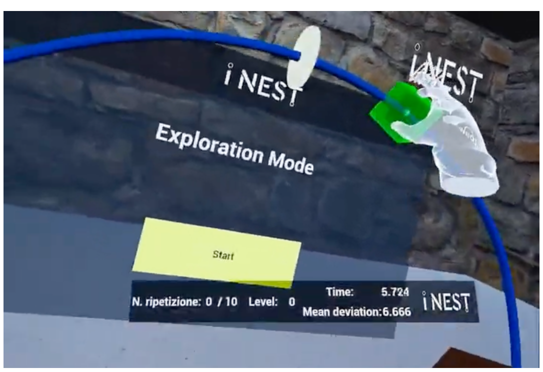

Figure 1. Rehabilitation exercise interface. The user guides the virtual cube along the reference spline while real-time performance metrics (time, and mean deviation) are displayed.

Framework and devices employed. The scenario consists of a user immersed in an interactive environment where they must move a virtual cube along a spline. The spline changes its shape according to the difficulty level selected based on the user's ability. An example of the environment is shown in Fig. 1.

The demo relies on two devices: (i) a Meta Quest 3 headset, and (ii) TouchDIVER G1 haptic gloves by Weart. The virtual environment has been developed in Unreal Engine, while the DDA framework has been implemented in Python.

Interactive XR rehab exercise with touch integration. The first component enables users to perform a rehabilitation exercise in an XR environment. The exercise targets patients undergoing upper-limb rehabilitation to train hand dexterity and improve fine motor skills. Key features include: (a) *Interactive environment:* Users interact with virtual objects and receive real-time feedback as they manipulate the cube along the target path. (b) *Touch perception:* The system delivers tactile feedback through the haptic gloves, enhancing realism and engagement and bridging the gap between visual and physical interaction.

Gamification and Dynamic Difficulty Adjustment in XR. The second component introduces challenge and progression, keeping patients mentally and physically engaged while improving (i) task-solving ability (cognitive stimulation) and (ii) movement quality and efficiency across repetitions. DDA is used to select the difficulty level that best supports improvement. Key features include: (a) *Performance scoring:* A scoring system evaluates accuracy and completion time, motivating patients and enabling progress tracking. (b) *GHMM-based level selection:* The DDA strategy is based on a Gaussian Hidden Markov Model (GHMM) trained on precision and time. Precision is computed as the distance between the trajectory of the cube center and the reference spline; time is the duration required to complete the exercise. The GHMM uses these features to select the most suitable difficulty level.

Conclusion. This demonstration provides a glimpse into the future of touch-integrated XR systems for rehabilitation. By combining haptic feedback devices, immersive environments, and gamification strategies, it lays the groundwork for more engaging and effective rehabilitation therapies. The use of a GHMM-based DDA framework allows modeling user capabilities and automatically scaling exercise difficulty based on performance, enabling personalized and adaptive rehabilitation experiences.